Coal Mine Reclamation and Remediation

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Glossary

acid mine drainage (AMD) Acidic water that drains or discharges from a mine; the acidity is caused by the oxidation of iron sulfide (FeS_2), or pyrite, which also causes the water to have elevated concentrations of sulfate and dissolved iron; also known as acid rock drainage (ARD), because the condition can result from non-mining-related pyrite exposure.

approximate original contour (AOC) A requirement that the final topographic configuration of backfilled and reclaimed surface-mined land approximate premining slopes and the general aspect of the premine topography.

bonding Mining companies are often required to post a bond to ensure that mined land will be properly reclaimed. The bond is typically released in phases, as remediation proceeds, either by recognizing successfully completed reclamation for part of the permitted area or by reclamation stages. In the latter case, most of the bond money is released when backfilling and regrading is completed, but some is kept for up to 5 years to ensure that revegetation remains adequate and self-sustaining and that water quality requirements are met. In the past, bond monies, when forfeited by companies that went bankrupt, were never adequate to reclaim a mine site and to treat the contaminated water, so government agencies are now requiring higher bonding levels.

coal refuse The waste left when raw coal is prepared or "cleaned" for market; usually contains a mixture of rock types, but is typically elevated in pyrite, causing it to be a source of acid mine drainage if not handled carefully. In the past, this material was simply piled up; nowadays, disposal requires compaction and stabilization measures.

fugitive dust The silt, dust, and sand that become airborne, carried away from a mine property by the wind.

mountaintop removal An often profitable but controversial method of surface mining in mountainous terrain where the coal seams lie beneath the ridge tops. All of the overburden is removed, exposing 100% of the coal for recovery. The controversy is due to the fact that the initial spoil must be placed in valley or head-of-hollow fills, though most of the subsequent spoil is placed on the level land left after mining proceeds. The final surface configuration, compared to the original landscape, has less relief.

Office of Surface Mining (OSM) A United States federal agency created by the Surface Mine Control and Reclamation Act of 1977, with responsibilities that include overseeing state enforcement of reclamation regulations, collecting fees per ton of coal mined, disbursing those funds (within the limits provided annually by Congress) to the states for reclamation of abandoned mined lands, and providing technical assistance and guidance to the states.

remining Reclamation of previously mined land by private companies, which extract the coal that was left behind by earlier mine operators; water treatment liabilities are not acquired by the new operator unless the new activity makes the water quality worse.

subsidence When fracturing and collapse of strata extend to the land surface; often associated with underground excavations.

Modern coal mines often cause environmental problems, but it must be recognized that these problems are much less extensive and less severe than those associated with mines that were abandoned before regulatory controls went into effect. The progress that has occurred over time is due in large part to the efforts of the environmental activists and the environmental regulations that they inspired, but it is also due, in part, to advances in technology that have made cost-effective environmental progress possible. Such technology can be used to avoid and prevent, or to reclaim and remediate, environmental problems.

1. INTRODUCTION

Any intensive use of the earth's resources carries with it potential environmental consequences. Mining is no exception. Historically, mining companies have extracted the earth's resources wherever economics made it feasible, secure in their knowledge that their products were essential to society. Prior to the passage of the Surface Mining Control and Reclamation Act in 1977, 1.1 million acres (445,000 ha) of coal-mined land in the United States was left unreclaimed and over 10,500 miles (16,900 km) of streams and rivers were adversely affected in the Appalachian region alone. At about the same time, 55,000 ha of mined land was left derelict in Great Britain, though not all of that was due to coal extraction. Although numbers are not readily available for other countries, it can safely be said that leaving land unreclaimed was common around the world during the time period prior to environmental legislation in the United States (Fig. 1).

However, over the past 25 years, a new generation of miners has taken over the industry. Most of these miners grew up with an environmental awareness, and have bought into the philosophy of environmentally responsible mining. Coal mining operations today are designed to comply with environmental regulations and to minimize adverse environmental impacts; exceptions exist, however, and serve to inspire environmental activists and conservation groups to resist and reject mining wherever it is proposed. This societal tension serves as a backdrop to the dynamics of issuing or rejecting mining permit applications.

FIGURE 1 Unreclaimed mine site; vegetation is largely volunteer growth.

2. POTENTIAL ENVIRONMENTAL PROBLEMS ASSOCIATED WITH COAL MINING

2.1 Surface Mines

The most obvious environmental effect of surface mining is the disruption of the land surface; surface mining is generally more visually obtrusive compared to underground mining. In most cases, coal occurs at depth and is covered by soil and rock that must be removed to allow access to the coal, leaving large holes and piles of removed material. Even when the coal outcrops on the land surface, removing the coal leaves a hole in the ground. At prelegislation mines, the land was sometimes left in a disrupted state, but mining companies are now required to separate topsoil from the overburden material, to fill in the excavation as mining proceeds, to cover the regraded land with topsoil, and then to revegetate the land surface. Moreover, in most countries, the regraded and reclaimed land has to be left in a final condition, the approximate original contour (AOC), that approximates the topography that existed before mining. Also, in the United States, bond money must be posted before mining is permitted; before the bonds can be released, the land must pass certain sustainable revegetation requirements, based on the premining soil conditions. For example, if the land was originally prime farmland, the reclaimed land must be productive enough to qualify as prime farmland (Fig. 2). Finally, the reclaimed land surface must be stable; measures must be taken to avoid erosion.

Given the fact that coal has been extracted, it might seem problematic to refill the excavated pit completely. In practice, the problem is typically the reverse; once the consolidated overburden rock is disrupted and broken, it cannot be placed in the same volume of space that it occupied before mining. Excess material (often called "spoil" or "fill") must be placed so as to be stable, either on level ground created during the mining process or in nearby valleys. At some sites, a pit is intentionally left and allowed to flood, providing a pond or small lake.

FIGURE 2 Properly regraded and reclaimed mined land.

This avoids the expense of hauling back spoil material already placed elsewhere, but the issue of water quality in such ponds, and indeed at all mine sites, is a key concern.

At many coal mines, iron sulfide (pyrite) associated with the coal and the overburden strata oxidizes on exposure; this produces water with elevated concentrations of sulfate, acidity, and dissolved metals. If there is sufficient alkalinity present (typically in the form of limestone), the alkalinity will neutralize the acidity. In such cases, the environmental impact on water quality may be relatively minor. However, if there is insufficient alkalinity, the water becomes acidic. This type of water is known both as acid mine drainage (AMD), in most coal-mining regions and especially in the eastern United States, or as acid rock drainage (ARD), in most metal ore-mining regions. The term ARD is also preferred by those who like to point out that the same water quality results from such rock exposure in road cuts and construction projects (e.g., the Halifax Airport). ARD can typically be recognized, wherever it occurs, by the color of the water, i.e., red or yellow-orange, which is caused by dissolved and suspended iron (Fig. 3).

The prediction of postmining water quality is a key component in obtaining a mining permit. This is typically determined by analyzing rock cores for pyrite and alkalinity-producing rock strata. Then, using one of several procedures, a prediction is made about whether the water will be acidic. If it appears that it will probably generate AMD, or have other adverse hydrologic consequences, the regulatory agency may deny permission to mine or require the mining company to undertake special measures to decrease the likelihood of AMD. For example, the mining company may be required to handle pyritic strata selectively, and place it in such a manner that it will be less exposed to air and/or water, or to mix it with the more alkaline rock strata, or to import additional alkalinity to the site.

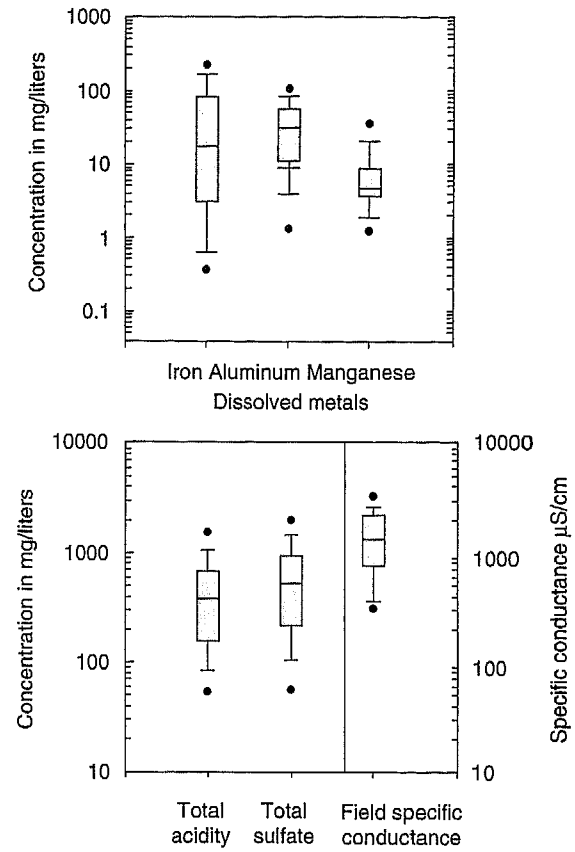

FIGURE 3 Range of contaminant concentrations in typical acidic coal mine drainage.

AMD can contaminate many miles of stream down-gradient from a mine, sometimes rendering it toxic to aquatic life. By regulation, any site that generates water not meeting regulatory standards (typically pH 6–9, no net acidity, iron less than 3 mg/liter, and manganese less than 2 mg/liter) must treat the water before it can be discharged. The water treatment must continue for as long as the untreated water fails to meet these discharge criteria. However, it should be noted that at surface mines, after the pyritic rock is buried, AMD typically moderates. Acid salts formed during exposure to the atmosphere continue to dissolve, but once these are dissipated, acid generation begins to decrease. It may take decades, but water quality, at even the worst of these sites, does improve.

In the United States, AMD is a major problem in Pennsylvania, northern West Virginia, western Maryland, and eastern Ohio, but also occurs at many mine sites in other states. Elsewhere in the world, acid drainage is often associated with coal mining, though the extent of the problem varies with local geology, site conditions, mining methods, etc. In the western United States, AMD is less likely to be a problem, due in part to the lower concentrations of pyrite associated with the strata there and in part due to the fact that the climate is drier. In fact, the lack of adequate precipitation can make reclamation difficult, and also introduces the problem of sodic spoils. Such materials are exposed during mining and contain elevated concentrations of sodium salts, which dissolve and add to the salinity of the soil and the downstream waterways.

Other environmental problems associated with surface mines include fugitive dust (airborne particles that blow away in the wind), ground vibrations and noise associated with blasting, loss or conversion of wildlife habitat, and loss of aesthetics (visual resources). The first two are temporary problems, but the latter two can be temporary or permanent, depending on the eventual land use. However, if an area is viewed as important to the life cycle of an endangered species, permit denial is almost certain. In contrast, mining companies sometimes take advantage of land disturbance and reclamation to enhance wildlife activity; for example, in the United States, an exception was granted to the AOC requirement to allow a mining company to establish an appropriate habitat for a bird that was native to the area but declining in population.

The lack of aesthetics generally attributed to mined and reclaimed land, though it varies with the individual site, generally refers to the fact that mined land is typically reclaimed in a bland and uniform manner. The lack of visual contrast, rather than the actual disturbance, is what is noticed. This is one, of many, objections that citizens often make about mountaintop removal, which is currently the most controversial form of permitted surface mining, and deserves to be specifically mentioned here. Mountaintop removal, or mountaintop mining, is used in mountainous areas such as southern West Virginia to extract multiple seams of coal over large areas. The excess overburden is placed in what were previously valleys, with French drains constructed to handle the intermittent stream flow that might have been there previously, though major drainage patterns are preserved. The original rugged ridge and valley appearance of the land is converted to a more sedate topography, creating usable flat land where before there was none, and typically reducing the hazard of storm-related flooding; local inhabitants, although they may appreciate the jobs brought to the area, find their neighborhood forever changed (some would say ruined). Local biota is of course affected as well. There have been numerous court fights attempting to end the practice of mountaintop removal, and it is not yet clear how the issue will finally be resolved, but an interesting and so far unexplained finding that elevated levels of selenium have been found downstream of West Virginia mountaintop removal operations may turn out to be significant.

2.2 Underground Mines

Although underground mine operations are not as visible as surface mining, their overall environmental impact can be greater than that of the typical surface mine. A key environmental problem is subsidence. Underground mines are large cavities in the rock, and depending on the strength of the intervening strata, the depth of the mine, and the type of mining and roof support, the rock walls can fail, causing cracks and land collapse at the surface. Typically, coal seams at depths greater than about 200 feet are extracted by underground mining methods rather than by surface mining, with the exact depth principally based on the relative amount of coal and overburden. However, before improved technology made surface mining so affordable, the trade-off occurred at much shallower depths; some abandoned underground mines are only 35 feet below the land surface.

In longwall mines, the subsidence is induced as mining proceeds. Most of the subsidence occurs within a few months after mining. Changes in surface elevation can be significant, affecting highways, waterways, etc., though mining beneath such features may be restricted. The extensive fractures and settling also disrupt aquifers, though deeper aquifers typically recover once the void spaces fill with water. In many European countries, where mining is centrally planned and directed, subsidence above longwall mines is typically anticipated and planned for (for example, in how buildings are constructed) years ahead of time. Elsewhere, where mining proceeds based on the decisions of mining companies and local and regional regulatory agencies, subsidence may be anticipated, but is rarely coordinated with other regional development activities. In contrast, more traditional room-and-pillar mining may resist subsidence for decades, failing only as pillars, left to support the overburden rock, erode and then collapse. The lateral extent of the subsidence area may not be as great as above longwall mines, but because the collapse is more localized, there is a greater risk of differential subsidence (for example, one corner of a house subsides more than the rest of the house, severely damaging or destroying it (Fig. 4). The ability to predict the extent of subsidence has improved over the past decade, but this is still a very inexact science.

The effect of subsidence on streams and waterways can be subtle or profound. In the worst cases, subsidence fractures reach the streambed and partially or totally drain the stream, diverting the water underground. Such fractures can be detected using terrain conductivity, and inexpensively sealed using an appropriate grout, but until that is done, the stream may go dry, and mining may be impeded or even temporarily halted. Even where waterways are not affected by subsidence fractures, the changes in slope will cause profiles to change, causing erosion in some areas and sediment deposition in others, and locally affecting stream biota.

Depending on the coal seam and location, AMD generation in underground mines can exceed that at surface mines. Because pyrite forms in a swampy environment, coal seams often contain more pyrite than do the overlying strata. At a surface mine, virtually all of the coal is removed, but in an underground mine, significant amounts of coal remain behind to provide roof support; if the coal is pyritic, it is problematic. In addition, alkalinity that may be present in the overburden strata is not as exposed to dissolution as it is when it is disrupted by surface mining. Finally, an underground mine is essentially a void, and behaves like a well; water flows through the surrounding rock into the mine void. When mining ceases and the water is no longer being pumped, the mine begins to flood and the water table rises. Thus, the volume of AMD that eventually discharges to the surface can be very great, completely overwhelming the buffering capacity of the receiving waterways. If the coal seam is completely inundated, the large mine pool will gradually improve in quality once all of the acid salts are washed away, because inundated pyrite does not continue to oxidize to a significant extent. However, coal seams typically slope (or "dip"); this may mean that only part of the seam is underwater, and the rest is continually exposed to the atmosphere, creating an ideal acid-generating environment that can continue to produce AMD for centuries.

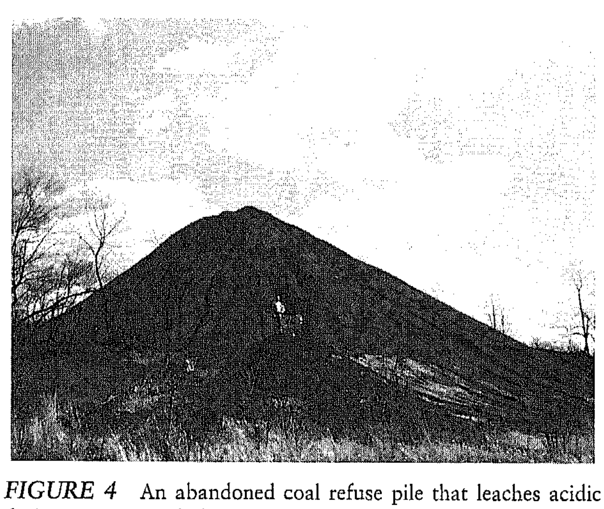

FIGURE 4 An abandoned coal refuse pile that leaches acidic drainage; many of these waste piles can be converted into a resource by burning the material in a fluidized bed combustion unit.

2.3 Refuse Piles

Mined coal often contains other rock types (e.g., shale and clay associated with the coal or lying immediately above or below the coal seam) and impurities (such as pyrite). Such coal is considered "high ash," because the impurities remain behind in the ash after combustion. To improve the coal value, such coal is typically crushed and "cleaned" or "washed" in a preparation plant. This process separates the coal from the waste material, which is transported to a disposal area. This coal refuse is typically very high in pyrite, low in alkalinity, and quite reactive because it has been crushed to a relatively fine grain size. Today, there are strict procedures on how the material must be compacted and covered; even so, AMD is a common problem. Abandoned piles of prelegislation coal refuse, which frequently lie in or near waterways, are problematic (Fig. 5). Such piles can generate extremely acidic mine drainage and sometimes catch on fire. However, many of these old waste piles contain quite a bit of coal, given the fact that coal cleaning procedures were not always as efficient as they are nowadays. Such piles can be converted into a resource, because the material can be burned in a fluidized bed combustion (FBC) unit.

2.4 The Environmental Legacy Associated with Abandoned and Orphaned Mines

Currently, site reclamation is planned for during the permitting process and is incorporated into the mining operation. However, this was not always the case. Many mine sites were legally abandoned in an unreclaimed or poorly reclaimed condition because mining was completed before environmental

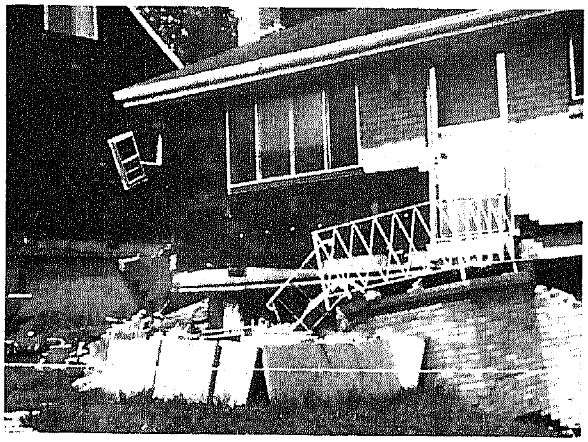

FIGURE 5 A house damaged by subsidence caused by the collapse of pillars in an abandoned underground mine.

FIGURE 6 Excavation and extinguishment of a burning coal refuse pile.

regulations went into effect. These abandoned mines are scars on the landscape and cause most of the water pollution attributed to mining. These old mines are considered abandoned because, in most countries, no one is legally required to reclaim the land or to treat the water. A similar problem occurs at mine sites that are or were operated by companies that have gone bankrupt. In theory, "bonds" (money held in escrow or guaranteed by a third party, required in many countries) posted by the companies will pay for reclamation and water treatment; however, at most sites, the amount of money required to reclaim the site exceeds the required bonds. In the United States, forfeiting a bond means that the company can no longer mine, so it is serious, but sometimes the costs of environmental compliance exceed the resources that a company has available. Several orphan underground mines are located near the Pennsylvania–West Virginia borders. These mines are gradually flooding with AMD, and are projected to begin discharging contaminated water to tributaries of the Monongahela River within the next 2 years. The anticipated contaminant load (contaminant concentration x flow) is such that it would have a major impact on water quality for many miles of the Monongahela River downstream; state and federal agencies are scrambling, trying to figure out what to do.

Regardless of whether a mine is abandoned or orphaned, the land remains inadequately reclaimed and the water that discharges from the site is typically not treated. In addition to the potential environmental problems associated with active mines, and already discussed, abandoned and orphan mines often have additional problems that can affect the health and safety of people who live in the area. For example, open pits with steep cliffs inevitably attract children, as do unsealed, unsafe underground mines. Unreclaimed waste rock piles and mine dumps pose a risk of slope failure and landslides. Another potential problem (discussed in detail in the next section) is mine fires, which are more typically viewed as a health and safety problem. However, at abandoned mines, such fires can smolder for decades, generating toxic gases that can flow through cracks into basements, and can accelerate subsidence events (Fig. 6).

So how are these problems dealt with? In the United States, the Surface Mining and Reclamation Act of 1977 (as extended and amended by the Abandoned Mine Reclamation Act of 1990 and the Energy Policy Act of 1992) did more than require mine operators to maintain environmental standards during mining and reclamation. It also imposed a fee of 35 cents/ton of coal mined by surface methods, 15 cents/ton of coal mined underground, and 10 cents/ton of lignite. These fees go into a fund managed by the Office of Surface Mining (OSM) in the U.S. Department of the Interior. This money can be used by the states and the OSM to address problems at abandoned mine sites. Most of these funds have gone to remediate sites that are hazardous to people and property, but increasingly funds are also being used to remediate environmental problems. These funds cannot be used to resolve problems at orphan mines.

In addition, regional and national governments have often provided additional funds for environmental remediation of abandoned sites. In particular, Pennsylvania should be singled out for its unique approach; it encourages the formation of watershed associations, which can apply for funds to remediate abandoned mines. Through the efforts of these enthusiastic volunteers, Pennsylvania accomplishes much more remediation than would be otherwise possible.

3. *LAND RECLAMATION*

Under natural conditions, a landscape represents a balance of geomorphic processes; this dynamic stability is disrupted by mining. In this context, the goal of reclamation is the reestablishment of the steady state. In the United States, regulations tightly control the reclamation process at active operations, dictating the slope (AOC), the extent of revegetation, and the rate at which reclamation and revegetation must proceed. Failure to comply results in loss of bond money and/or fines. Other countries (e.g., Canada) have more flexibility built into their regulatory structure. They consider the imposition of AOC inappropriate at many sites—for example, in areas where flat land would be desirable; enhanced flexibility allows such aspects to be negotiated. In the United States, exceptions can be granted by the OSM, but are atypical. Instead, operators have learned to operate within the limits of the regulation. For example, they may choose to reduce erosion potential on steep slopes by installing terraces and manipulating infiltration rates.

When reclamation agencies are attempting to reclaim derelict or abandoned operations, no attempt is typically made to restore the land to AOC. Instead, the primary intent is to remove potential hazards (e.g., extinguish potentially dangerous mine fires, seal mine openings); secondarily, the intent is to bury acid-forming material, and, finally, to create a stable surface that will resist erosion with minimal maintenance. Funds for reclamation of abandoned sites are quite limited and represent a small fraction of what would be necessary to reclaim all abandoned mine sites.

Many abandoned sites have developed a natural, if sometimes sparse, vegetative cover of volunteer species. In addition, an unusual incentive has recently developed that may encourage companies to reclaim abandoned sites that have not naturally revegetated. As pressure gradually grows on companies to lower carbon emissions, proposals have been made that credit should be given for revegetating barren lands, because this would sequester carbon from the atmosphere. Arid deserts and barren abandoned mine sites are the two most likely types of places for such an effort, if and when it becomes codified.

Another aspect of mined land remediation is subsidence control. Because subsidence events above old room-and-pillar operations commonly cluster, when subsidence begins in an area, state and OSM emergency personnel are quickly mobilized. Typically, they attempt to backfill, inject, or stow, hydraulically or pneumatically, as much solid material into the mine void as possible, figuring that reducing the void volume with fine solids (sand, fly ash, etc.) will both decrease the amount of subsidence that will occur and reinforce pillars that might otherwise fail. However, because the mine voids that they are injecting the material into are often flooded, it is sometimes difficult to ascertain if these efforts make much of a difference. An alternative option pursued by many landowners in undermined areas is government-subsidized subsidence insurance. This insurance fund pays property damage after subsidence has occurred.

4. *MINE WATER REMEDIATION*

Before the passage of regulations dictating mined land reclamation and mine water discharge standards, streams and rivers down-gradient of mine sites were often contaminated with high levels of suspended and dissolved solids. In the eastern United States, AMD was also a major problem. Nowadays, streams and rivers near active mine sites have much less of an impact. Sediment ponds are constructed to collect suspended solids and if the mine water does not meet regulations, chemicals [typically lime, $Ca(OH)_3$] are added to neutralize acidity and precipitate dissolved metals. Consequently, the remaining sources of contaminated water discharging to streams and rivers in mined areas are generally from abandoned or orphan mines. However, before moving on to water remediation at such sites, the techniques used to prevent, ameliorate, or remediate mine water problems at active operations need to be addressed. As alluded to previously, a powerful tool in preventing AMD is the permitting process. Variation exists in how much certainty of AMD generation a regulatory agency requires before a permit is denied. In the United States, Pennsylvania is the most conservative, and can legitimately boast that it has improved the accuracy of its permitting decisions from about 50% in the 1980s to 98%; however, it should be noted that this definition of success is based on AMD generation at permitted operations (following reclamation) and does not include mine sites that had permits denied and might not have produced AMD if allowed to operate.

In contrast, adjacent states (and many areas outside of the United States) permit a higher percentage of mines to operate, but generally require that measures be taken to reduce the risk of acid generation. In addition to the selective handling of overburden and the importation of alkalinity from off-site mentioned earlier, minimizing exposure of the pyrite to either oxygen or water can decrease the amount of acidity generated. Restricting exposure to oxygen generally means that the pyritic material must be placed beneath the eventual water table, which is difficult to do at many surface mines. Alternatively, the operator can attempt to place the pyritic material in an environment where it is dry most of the time, well above the potential water table and capped by material of low permeability. Compaction can also be used to reduce permeability, though not on the final soil surface, where compaction makes it difficult to establish a vegetative cover. Water can be diverted around the mine site by intercepting overland flow with ditches, and by constructing drainage ways along the final highwall to intercept groundwater and prevent it from flowing through the overburden material.

At many sites, mining companies have been given special permission to remine old abandoned mines to improve water quality. The mining companies harvest coal left behind by the old operations. For example, old room-and-pillar mines sometimes left as much as 50% of the coal behind to support the roof rock. Some of these old mines are relatively shallow and can be inexpensively surface mined using modern machinery. Because the coal pillars are sources of acid generation, removing them generally improves water quality. Similarly, old surface mines could not economically remove as much overburden as is now possible. The exposed highwall can now be economically mined with modern machinery. The mining companies are required to reclaim the land to current standards, but their water discharge requirements typically only require them to at least meet the water quality that existed before the remining operation. In most cases, the water quality improves and the land is reclaimed, at no cost to the public.

A more exotic approach of controlling AMD involves the inhibition of iron-oxidizing bacteria. These ubiquitous bacteria normally catalyze pyrite oxidation; inhibiting them reduces acid generation significantly. In practice, however, it is difficult to do this. The only cost-effective approach that has been developed involves the use of anionic surfactants (the cleansing agents in most laundry detergents, shampoos, and toothpaste); their use selectively inhibits the iron-oxidizing bacteria by allowing the acidity that they generate to penetrate through their cell walls. This approach has been used effectively to treat pyritic coal refuse, reducing acid generation 50–95%. Slow-release formulations have been developed for application to the top of the pile before topsoil is replaced and the site is revegetated.

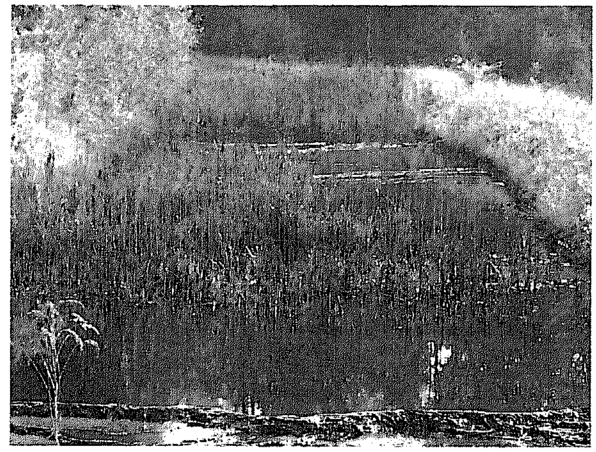

FIGURE 7 Mine water can be directed through a specially constructed wetland to passively improve the water quality.

Discharge criteria must be met, and if the at-source control measures are not completely effective, some form of water treatment is required. Sometimes water treatment is required only during the mining and reclamation operation, and water quality improves soon after reclamation is completed. Sometimes the water quality remains poor. Chemical treatment is simple and straightforward, but is expensive to maintain for long periods.

Passive and semipassive water treatment technologies, though by no means universally applicable, are an option at many sites. These techniques developed as a result of observations at natural and volunteer wetlands, which were observed to improve the quality of mine drainage. The simplest of these techniques, appropriate for near-neutral mine water that is contaminated with iron, involves the construction of shallow ponds, planted with plants that will tolerate the water, such as *Typha* (commonly called cattails in North America) (Fig. 7). The iron in the water oxidizes and precipitates in this constructed wetland instead of in the stream, allowing natural stream biota to repopulate. These constructed wetlands cannot be viewed as equivalent to natural wetlands; they have been designed to optimize water treatment, and any associated ecological benefits, though they may be significant, have to be viewed as secondary.

Water that is acidic can be neutralized by the inexpensive addition of alkalinity. Several passive methods have been developed, generally using limestone and/or sulfate-reducing bacteria. Alkaline waste products (e.g., steel slag) have also been used. Water quality, site considerations, and flow dictate which approach is most cost-effective at a given location.

The realization that passive techniques can be used to treat low to moderate flows of mine water has made it possible for state reclamation agencies and local watershed associations to remediate mine water at abandoned and orphan mines without a long-term financial commitment for chemicals. However, highly contaminated AMD or high flows still cannot be cost-effectively treated passively. But the technology is continuing to evolve. Semipassive techniques, such as windmills and various water-driven devices, are being used to add air or chemical agents to mine water, extending and supplementing the capabilities of the passive treatment technologies.

Contaminated water in abandoned or orphan underground mines represents the ultimate challenge because of the large volume of water that must be treated. One option currently being explored in the United States is whether or such mine pools can be used as cooling water for a power plant. Locating new power plants is becoming more difficult because of the water needed for cooling purposes. A large mine pool could be a good resource for such an operation. The power plant would have to treat the mine water chemically, but this cost could be partially subsidized by the government, which would otherwise have to treat the water chemically or allow the mine discharge to flow untreated into the local streams and rivers.

5. OTHER ENVIRONMENTAL ASPECTS

The issue of aesthetics has already been introduced. In many ways, it can be the most challenging obstacle to popular acceptance of mining in an area, because, to many, anything less than complete restoration of the land is unacceptable. However, mine operators have learned to minimize the aesthetic impact of mining by avoiding extremely visible sites, by using screens (e.g., trees left in place as a visual barrier or revegetated topsoil stockpiles placed in locations where they hide the mine pit from view), by minimizing the duration of impact, and by ensuring that regrading and revegetation proceeds as quickly as possible.

Finally, the issue of ultimate land use of the reclaimed land must be considered. Nowadays, this is actually addressed as part of the permitting process. Some mine operators have successfully created planned industrial sites, some have created highly productive farmland, but much of the mined land is reclaimed for wildlife use. Costs for seed and plantings are relatively low, and plans are often coordinated with local conservation groups to reclaim the land in an appropriate manner for wildlife use. To be effective in this regard, these reclaimed lands must be physically connected to other areas where such wildlife currently exists; isolated fragments of habitat will not serve the desired purpose of restoring wildlife use disrupted by mining activity and road construction. With regulatory approval, ponds can be left in locations where they will serve migratory bird populations or provide watering areas for permanent wildlife populations.

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